Predicting nitrogen fertilizer requirements for corn by chlorophyll meter under different N availability conditions

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Rashid, M. T., Voroney, P. and Parkin, G. 2005. **Predicting nitrogen fertilizer requirements for corn by chlorophyll meter under different N availability conditions**. Can. J. Soil Sci. **85**: 149–159. Nitrogen management strategies that enhance fertilizer use efficiency and maximize profitability in corn require a rapid and accurate method to determine the crop N needs of current hybrids. The objective of this study was to evaluate the potential of a portable chlorophyll meter for predicting N fertilizer requirements for corn grown under varying levels of N availability. Several crop management treatments were imposed in an attempt to create conditions ranging from low N availability (oily food waste application in spring and fall, application at different rates in spring) to high N availability (continuous fertilized corn, winter wheat cover crop). Different corn hybrids were sown at different sites (21 site yr) and varying N fertilizer application rates were applied. Chlorophyll meter readings (CMR) were taken at the 5th to 6th leaf stage (V_6) using a SPAD-502 chlorophyll meter. The crop management treatments, corn hybrids and their interaction significantly affected the chlorophyll meter readings. A high inverse correlation between chlorophyll meter readings and maximum economic rate of nitrogen (MERN) was observed (r = –0.87). The main new and unique aspect of our research is the development of a linear model for using chlorophyll meter measurements to make N fertilizer recommendations (MERN = 348.47 – 8.5304 × CMR) for corn production under varying degrees of N availability in Southern Ontario.

Key words: Chlorophyll meter, soil organic carbon, nitrogen application

Rashid, M. T., Voroney, P. et Parkin, G. 2005. **Prévision des besoins en engrais azotés du maïs par dosage de la chlorophylle selon la quantité d'azote disponible**. Can. J. Soil Sci. **85**: 149–159. Pour mieux utiliser les engrais et rentabiliser au maximum le maïs, la gestion de l'azote suppose l'usage d'une méthode permettant d'établir rapidement et avec précision les besoins en engrais N des hybrides cultivés. L'étude devait évaluer l'utilité d'un appareil portatif servant à doser la chlorophylle pour établir les besoins en engrais N du maïs cultivé dans des sols contenant une quantité variable de N assimilable. Les auteurs ont recouru à diverses pratiques culturales pour engendrer les conditions voulues, soit une faible (application de déchets alimentaires huileux au printemps et à l'automne, variation du taux d'application au printemps) à une grande quantité (fertilisation continue, culture-abri de blé d'hiver) de N disponible. Ils ont semé divers hybrides de maïs à différents endroits (21 sites-années) et appliqué un taux variable d'engrais azotés. Ensuite, ils ont dosé la chlorophylle au stade de la 5^{e}-6^{e} feuille (V_6) avec un lecteur SPAD-502. Les pratiques culturales, l'hybride et leurs interactions affectent significativement les relevés. Les résultats obtenus avec le lecteur présentent une très forte corrélation inverse avec le taux d'application maximal économique d'engrais azoté (TAME) (r = –0,87). La principale innovation et le caractère unique de cette étude consistent en l'élaboration d'un modèle linéaire utilisant la concentration de chlorophylle pour formuler des recommandations sur l'application d'engrais azotés (TAME = 348,47 – 8,5304 x quantité de chlorophylle) pour la culture du maïs selon la quantité de N disponible dans le sud de l'Ontario.

Mots clés: Dosage de la chlorophylle, carbone organique dans la sol

Developing an ability to predict the N requirements for maximizing economic corn crop production has been an important issue since N fertilizers became widely available. Increased public concerns about drinking water pollution with nitrates and of emissions of greenhouse gases such as nitrous oxides and ammonia have made it mandatory to justify N fertilizer recommendations both in economic and environmental terms. This has resulted in more emphasis on N fertilizer use efficiency in recent years.

Assessment of several soil and plant test methods that could improve N management for corn has been reported in the literature (Magdoff et al. 1984; Blackmer et al. 1989; Fox et al. 1989; Binford et al. 1990; Hong et al. 1990). All of these N testing methods involve some combination of soil or tissue sample collection and drying, sample grinding and screening, and finally sample analysis with either laboratory or portable field instruments. The disadvantages of these methods are the extensive effort required for sample collection and processing and the time delay from sampling until

Abbreviations: **CC**, conventional corn; **CMR**, chlorophyll meter readings; **FFOG**, FOG applied in fall; **FOG**, fat, oil and grease; **MERN**, maximum economic rate of nitrogen application; **SFOG**, FOG applied in spring; **SOC,** soil organic carbon; **WWC**, winter wheat cover crop

Table 1. Crop management conditions and site description of all experiments where chlorophyll meter readings were taken during 1995, 1996 and 1997

#	Year	Location	Crop management treatments	Soil texture
1	1995	Elora (Site 1)	Conventional corn[z]	Silt loam
2	1995	Elora (Site 2)	WWC[y]	Silt loam
3	1996	Elora (Site 3)	Conventional corn	Loam
4	1996	Elora (Site 4)	WWC	Loam
5	1996	Elora (Site 5)	Conventional corn	Silt loam
6	1996	Elora (Site 6)	FFOG-10[x]	Silt loam
7	1996	Elora (Site 7)	SFOG-10[w]	Silt loam
8	1996	Elora (Site 8)	WWC	Silt loam
9	1997	Elora (Site 9)	Conventional corn	Loam
10	1997	Elora (Site 10)	FFOG-10	Loam
11	1997	Elora (Site 11)	SFOG-10	Loam
12	1997	Elora (Site 12)	WWC	Loam
13	1996	Elora (Site 13)	Conventional corn	Silt loam
14	1996	Elora (Site 14)	SFOG-10[v]	Silt loam
15	1996	Elora (Site 15)	SFOG-20[u]	Silt loam
16	1995	Bellwood (Site 16)	SFOG-10 at top slope position[t]	Sandy loam
17	1995	Bellwood (Site 17)	SFOG-10 at mid slope position	Sandy loam
18	1995	Bellwood (Site 18)	SFOG-10 at lower slope position	Sandy loam
19	1996	Bellwood (Site 19)	SFOG-10 at top slope position[u]	Sandy loam
20	1996	Bellwood (Site 20)	SFOG-10 at mid slope position	Sandy loam
21	1996	Bellwood (Site 21)	SFOG-10 at lower slope position	Sandy loam

FOG = oily food waste.
[z]Continuous corn
[y]Winter wheat cover crop planted in fall and incorporated in spring.
[x]FOG applied in fall season at 10 Mg ha^{-1}.
[w]FOG applied in spring season at 10 Mg ha^{-1}.
[v]FOG applied in spring season at 10 Mg ha^{-1}.
[u]FOG applied in spring season at 20 Mg ha^{-1}
[t]Field having rolling topography with 0–6% slope.
[u]Field having rolling topography with 0–9% slope.

the N test result is obtained (Magdoff et al. 1990; Sander et al. 1994).

Crops respond to N deficiency and manifest visual deficiency symptoms. It is obvious that if nutrients in the soil are available for absorption by the plant, a direct measure of the plant vigour should be a useful indicator of nutrient availability. Nitrogen is part of the enzymes associated with chlorophyll synthesis (Chapman and Barreto 1995) and the chlorophyll concentration reflects relative crop N status and yield level (Blackmer and Schepers 1995). This has made it possible to use leaf chlorophyll content measured by a chlorophyll meter to estimate crop N status and thereby determine the need for additional N fertilizer. A positive correlation between chlorophyll content and leaf N concentrations has also been reported (Girardin et al. 1985, Wolfe et al. 1988, Lohry 1989; Wood et al. 1992).

Corn plants under N stress show chlorosis or yellowing and this deficiency can easily be detected early in the corn-growing season i.e., the fifth to sixth leaf stage, the time at which N fertilizer is side dressed. In a practical sense, chlorophyll meters have been shown to be an effective tool for identifying sites that are responsive and non-responsive to side-dressed N (Piekielek and Fox 1992). This instrument is considered a convenient tool for evaluating the N status of a corn crop in the early part of the crop-growing season (Piekielek and Fox 1992; Schepers et al. 1992b; Binder et al. 2000). Chlorophyll meter readings at higher N levels suggest that the instrument is not sensitive to luxury consumption of N when N is sufficient, which makes it ideal for detecting N deficiency (Schepers et al. 1992b; Dwyer et al. 1995).

A variety of non-hazardous organic wastes can be applied to agricultural soils. One of these organic wastes is oily food waste produced by food service and food processing industries. This material contains high concentrations of fat, oil and grease derived from animal and vegetable sources. In Ontario the amount of oily food waste available for land application annually is 450 000 Mg (ORMI 2003). The application of oily food waste, which has a high C:N ratio (90:1), will immobilize soil N and reduce plant available N during its decomposition (Rashid and Voroney 2004). Observations of high rates of decomposition and regular patterns of N immobilization and mineralization are common in studies involving different oils (Smith 1974; Higuchi and Kurihara 1980), volatile fatty acids (Kirchman and Lundvall, 1993; Sorensen, 1998) and oily food waste (Plante and Voroney 1998). Plante and Voroney (1998) reported that N immobilized during the decomposition of oily food waste is expected to be subsequently mineralized and available to the succeeding crop.

Most of the literature regarding the use of a chlorophyll meter as a tool to recommend N fertilizer rate for corn was based on studies with conventional corn production practices. Information regarding the use of a chlorophyll meter to recommend N fertilizer for corn grown on soils treated with organic waste, such as oily food waste (FOG), where available soil N is immobilized due to the application of carbon substrates and severe N deficiencies are expected in the

Table 2. Chemical properties different experimental sites at Elora Research Station and Farmer's field in Bellwood

#	Crop management conditions	Year	pH	SOC	Total N	Available P	Amm. acetate extract-K	2M KCl NO_3-N
					Soil depth (cm)			
					0–15 (g kg^{-1})		0–30 (mg kg^{-1})	
1	Conventional corn[z]	1995	7.5	18	1.26	16	53	14
2	WWC[y]	1995	7.6	20	1.31	18	56	13
3	Conventional corn	1996	7.8	21	1.23	14	71	14
4	WWC	1996	7.4	24	1.17	18	79	15
5	Conventional corn	1996	7.7	19	1.25	19	64	14
6	FFOG-10[x]	1996	7.8	22	1.32	20	71	17
7	SFOG-10[w]	1996	7.5	24	1.31	15	59	7
8	WWC	1996	7.5	26	1.36	19	63	17
9	Conventional corn	1997	7.1	29	1.35	17	71	16
10	FFOG-10	1997	7.4	27	1.24	16	77	17
11	SFOG-10	1997	7.6	21	1.35	17	72	6
12	WWC	1997	7.3	24	1.32	18	74	15
13	Conventional corn	1996	7.4	18	1.24	15	86	14
14	SFOG-10[v]	1996	7.7	22	1.11	18	84	5
15	SFOG-20[u]	1996	7.3	21	1.21	16	82	2
16	SFOG-10 at Upper slope	1995	7.5	24	1.25	23	87	19
17	SFOG-10 at Mid slope	1995	7.1	22	1.22	22	82	12
18	SFOG-10 at Lower slope	1995	6.9	31	1.42	25	99	32
19	SFOG-10 at Upper slope	1996	7.3	23	1.24	22	92	22
20	SFOG-10 at Mid slope	1996	7.5	22	1.23	20	85	18
21	SFOG-10 at Lower slope	1996	7.1	35	1.62	23	102	31

SOC = Soil organic carbon
[z]Continuous corn
[y]Winter wheat cover crop planted in fall and incorporated in spring.
[x]FOG applied in fall season at 10 Mg ha^{-1}.
[w]FOG applied in spring season at 10 Mg ha^{-1}.
[v]FOG applied in spring season at 10 Mg ha^{-1}.
[u]FOG applied in spring season at 20 Mg ha^{-1}.

Table 3. Chemical analysis of oily food waste applied at different sites

Site	pH	EC (S m^{-1})	Solids content (%)	Total C in solids (g kg^{-1})	Total N in solids (g kg^{-1})	C:N
SFOG[z]	4.6	7.3	15	810	9.20	88
SFOG	4.5	7.6	17	820	9.40	87
SFOG	5.0	7.2	18	860	8.90	97
FFOG[y]	4.6	7.4	16	850	10.00	85
FFOG	4.7	7.5	17	842	9.79	86
Top slope position[x]	4.5	7.8	15	835	9.94	84
Mid slope position	4.5	7.8	15	835	9.94	84
Lower slope position	4.5	7.8	15	835	9.94	84
Top slope position[w]	4.6	7.3	18	852	9.91	86
Mid slope position	4.6	7.3	18	852	9.91	86
Lower slope position	4.6	7.3	18	852	9.91	86

[z]SFOG = FOG applied in spring season.
[y]FFOG = FOG applied in fall season after Corn harvest.
[x]Field having rolling topography with 0–6% slope and FOG was applied in spring.
[w]Field having rolling topography with 0–9% slope and FOG was applied in spring.

early growing season, is scarce. The information generated for soils amended with organic waste material will be useful to expand the knowledge regarding the use of a chlorophyll meter for N fertilizer recommendations for a wide range of crop and soil management conditions.

Field experiments were conducted to test a chlorophyll meter as a tool to make N fertilizer recommendations for corn grown under varying degrees of N availability ranging from high to very low. A series of treatments was established at selected sites to represent a range of soil N availability levels, and a range of N fertilizer rates were then superimposed in order to assess corn responses to N under a range of soil N availability. The crop management treatments include, conventional corn (CC), application of oily food waste at 10 Mg ha^{-1} in fall (FFOG) and in spring (SFOG), applied in spring at different rates (10 and 20 Mg ha^{-1}; SFOG-10 and SFOG-20), winter wheat cover crop incorporation (WWC), and application of oily food waste in

Table 4. Effect of crop management treatments and corn hybrids on chlorophyll meter readings (ANOVA)

Source	DF	Type III SS	MS	F	Pr > F
Model	74	27166.35	367.11	72.72	***
N	1	2288.15	2288.15	232.76	***
N × N	1	735.77	735.77	74.85	***
CMT[z] × HYB[y]	24	1461.10	60.88	12.39	***
N × CMT × HYB	24	818.10	34.09	6.94	***
N × N × CMT × HYB	24	432.20	18.01	3.66	***
Error	345	1872.35	5.43		
Corrected total	419	34774.02			
Line contrasts					
Hybrids					
a. DK306 vs. P3906	3	1028.22	342.74	63.15	***
b. DK306 vs. P3905	3	278.97	92.99	17.13	***
c. P3906 vs P3905	3	165.58	55.19	10.16	***
Crop management treatments at Elora					
a. SFOG vs. CC	3	658.36	219.45	40.44	***
b. SFOG vs. FFOG	3	430.41	143.47	26.44	***
c. SFOG vs. WWC	3	252.92	84.31	15.53	***
Crop management treatments at on-farm					
a. Top vs Lower	2	635.97	317.99	58.59	***
b. Top vs. Mid	2	476.98	238.49	43.94	***
c. Mid vs. Lower	2	508.78	254.39	46.87	***

R^2	*C.V*	*RMSE*	*CMR mean*
0.88	6.197	2.22	35.78

[z]CMT = crop management treatments viz:

At Elora:	On-farm At Bellwood:
CC = conventional corn	Top = top slope position
FFOG = fall-applied food waste	Mid = mid slope position
SFOG = spring-applied food waste	Lower = lower slope position
WWC = winter wheat cover crop	

[y]HYB = Hybrids viz.: DK- 343, DK- 352, DK- 306, Pioneer- 3905 and Pioneer- 3906

*** = < 0.001

spring at 10 Mg ha^{-1} at different landscape positions (top, mid and lower slope).

In N management studies, the Cate and Nelson (1965) approach is adopted to separate responsive and non-responsive sites, which predicts the critical level of a plant N status, above which no N fertilizer is required. This approach has the problem of predicting N fertilizer requirements below the critical point, as the exact amount of N fertilizer to be applied cannot be predicted precisely. Instead of adopting the Cate and Nelson approach we adopted the approach of correlating maximum economic rate of N application (MERN) with chlorophyll meter readings (CMR) to overcome the previously mentioned difficulty.

Maximum economic rate of N application is being used as an agronomic indicator to make N fertilizer recommendations to corn in Ontario [Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) 1996]. The objective of the study was to assess the potential of a chlorophyll meter for making N fertilizer recommendations for corn grown under varying soil N availability conditions.

MATERIAL AND METHODS

Crop Management Treatments and Experimental Designs

Several experiments (representing different N availability conditions induced by different crop and FOG waste management conditions) were conducted at farmer's fields in Bellwood and at Elora Experimental Research Farm in Ontario, Canada during 1995–1997. All experiments were set out as a randomized complete block design with four replications. Details regarding location, crop management treatment, their description and soil types of experimental sites are given in Table 1. Soil fertility analysis is presented in Table 2.

Conventional corn fields were representative of continuous corn where no amendments were used for the past 5 yr. The WWC (*Triticum aestivum* 'Harus') was planted in October (fall) and the crop was incorporated into the soil prior to boot stage in May next spring. Four samples of WWC were taken from each replication by harvesting a 1 m^2 area in spring prior to incorporation in the soil and oven dried to determine the quantity of cover crop residues added to soil. The total quantities of WWC biomass (C:N = 14:1) incorporated in soil in 1996 and 1997 were 1.48 and 1.26 Mg ha^{-1}, respectively.

Oily food waste (15–18% solid content; Table 3) was applied as organic waste in spring at 10 Mg ha^{-1} (solid content) at different slope positions (upper, mid and lower) at on-farm sites by using the commercial liquid manure applicators. FOG waste at Elora research station was applied at different rates in spring (10 and 20 Mg ha^{-1}) and times of application (fall and spring) at the same rate (10 Mg ha^{-1}) using a 1000-L vacuum-operated slurry spreader. The FOG

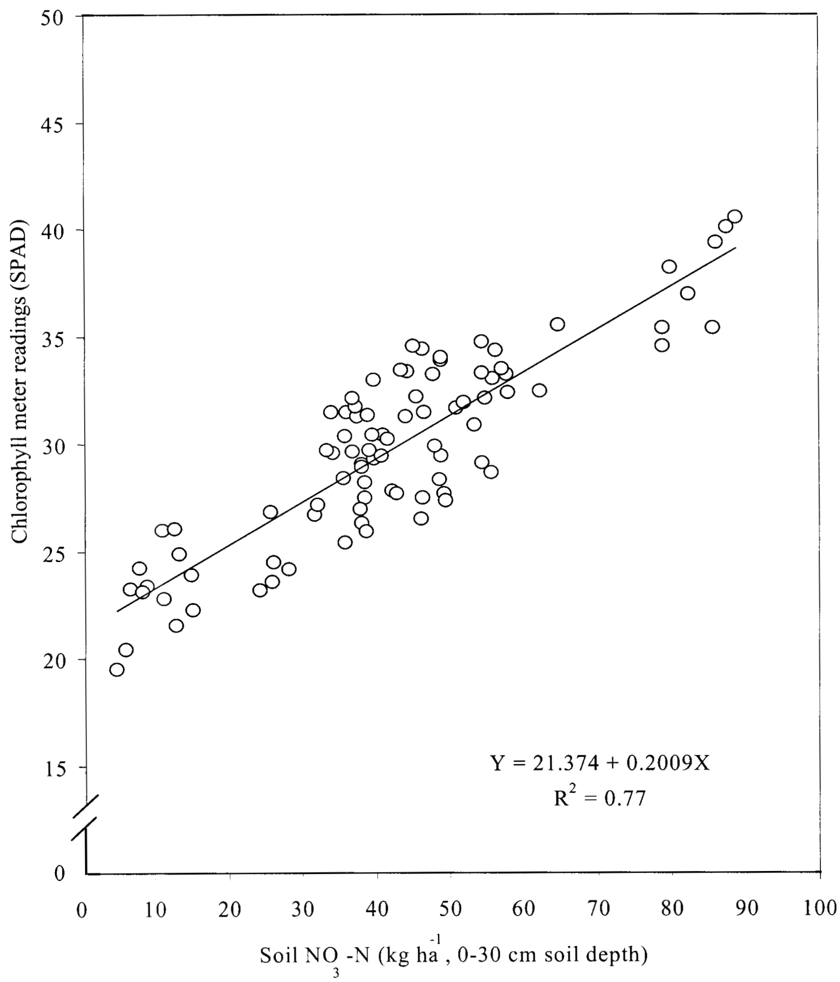

Fig 1. Relationship between soil NO_3-N content and chlorophyll meter readings of corn at the 5th to 6th leaf stage (soil samples and readings were taken at the same time).

waste was kept well mixed in a liquid manure tank (12 000 L) and measured quantities were applied to individual plots. The surface soil was allowed to dry (2–4 h) before the oily food waste was incorporated to the soil by moldboard plow.

Nitrogen as urea was applied at 0, 50, 100, 150 and 200 kg N ha^{-1} to all experiments. Urea as N fertilizer was hand broadcast and incorporated by a cultivator into soil at all locations before corn crop seeding. Five field corn (*Zea mays* L.) hybrids (DK-306 and DK-343 at the on-farm plots; DK-352, Pioneer-3905 and Pioneer-3906 at Elora Research Farm experimental plots) were planted (65 000 plants ha^{-1}) during the 3rd wk of May during 1995–1997. Starter fertilizer (NPK 0-20-20) was applied at 100 kg ha^{-1} at the time of planting to all experimental plots.

Chlorophyll Meter Readings

Leaf chlorophyll meter readings (CMR) were taken from corn plants at all experimental sites at the five- to six-leaf stage (V_6) with a SPAD-502 chlorophyll meter (Minolta Corporation). Chlorophyll meter readings (40 from each plot) were taken at leaf 5 or 6, whichever was fully emerged, from 10 plants along two central rows of each plot. Four readings, two on each side of the mid-rib and the central part of the leaf, were taken (Piekielek and Fox 1992).

Plant, Soil Sampling and Analysis

The same leaves were detached for nitrogen analysis to correlate the CMR with N concentrations in the leaf. Corn plant leaves were oven dried (60°C), ground to pass a 0.5 mm mesh, and analyzed for total N by the Dumas method using a LECO instrument (Tabatabai and Bremner 1970). Soil samples from each experimental site were taken for soil fertility analysis and were analyzed for pH (Peech 1965), SOC (Tiessen and Moir 1993), total N (McGill and Figueiredo 1993) available P (Olsen and Somers 1982) and available K (McLean and Watson 1985).

Soil samples from the 0 N plots were taken from the 0- to 30-cm soil depth for soil NO_3-N analysis. Six soil cores were drawn from the center of each plot and mixed to make one sample. Soil samples were immediately transported to lab and kept under –8°C. Frozen samples were thawed and sieved wet (2 mm sieve) to extract with 2 M KCl (Keeney

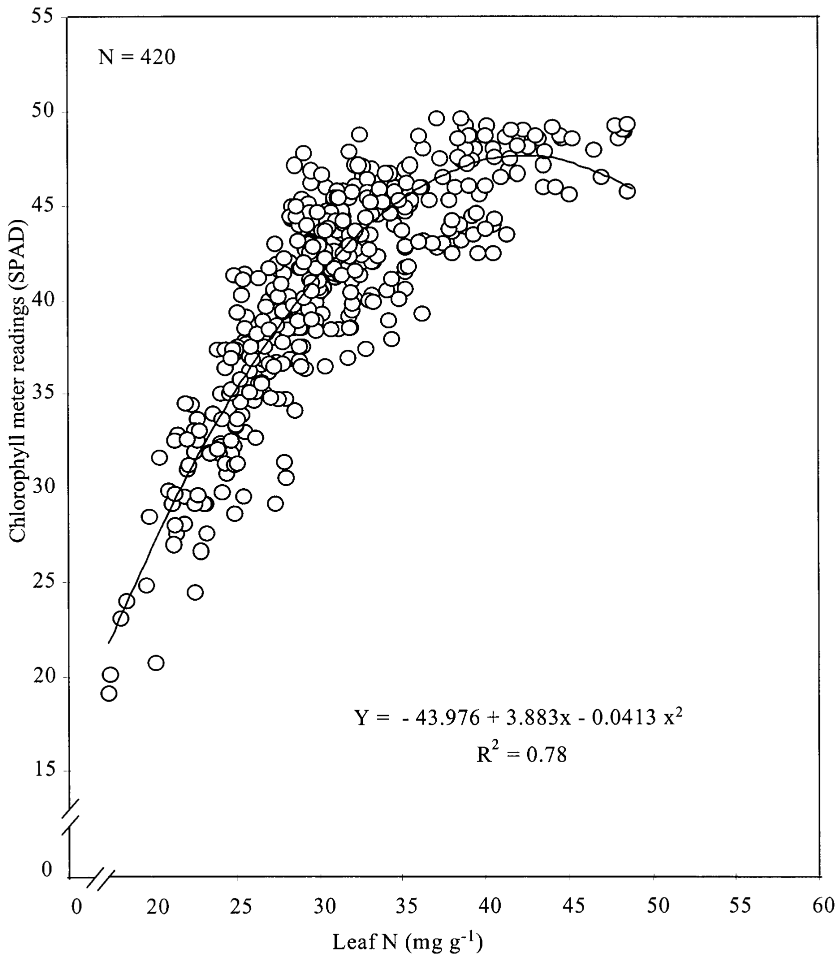

Fig 2. Relationship between chlorophyll meter readings and leaf N concentration of corn at the 5th to 6th leaf stage under different crop management conditions.

and Nelson 1982). The extract was analyzed for NO_3-N with a TRAACS-800 instrument (Tel and Heseltine 1990). Soil NO_3-N data were used to confirm the availability of N in soil as a recommended procedure adopted by Ontario Ministry of Food and Rural Affairs (OMAFRA 2002).

Maximum Economic Rate of Nitrogen

Corn grain yield was determined by harvesting two central rows from each plot (1.76 × 5 m). The MERN for each field crop management condition was calculated separately by following the method proposed by McGonigle et al. (1996):

$$Y = a + bN - cN^2 \tag{1}$$

where Y = corn grain yield (kg ha^{-1}), N = fertilizer N applied (kg ha^{-1}), and a, b, c = coefficients of quadratic response equation.

The derivative of the quadratic response equation:

$$dY/dN = b - 2cN \tag{2}$$

Where R^* = the ratio of price of 1 kg of fertilizer N to the price of 1 kg of corn grain.

Therefore,

$$R = b - 2cN \tag{3}$$
$$N = (b - R)/2c$$

or when

$$N = MERN$$
$$MERN = (b - R)/2c. \tag{4}$$

R^* = 7 is used for MERN calculations and is calculated for the current (2004) N fertilizer and corn grain prices. Corn price at present = $0.13 per kg grain and N fertilizer price = $0.91 per kg.

Statistical Analysis

Statistical analyses of the data were performed by PROC GLM SAS procedure (SAS Institute, Inc. 1996). A quadratic model was used to analyze the effects of different factors on chlorophyll meter readings. After initial analysis the data set was divided into two groups to determine the effects of different crop (Elora) and field management (On-farm) conditions and corn hybrids on CMR by contrast comparisons and are reported separately in Table 4.

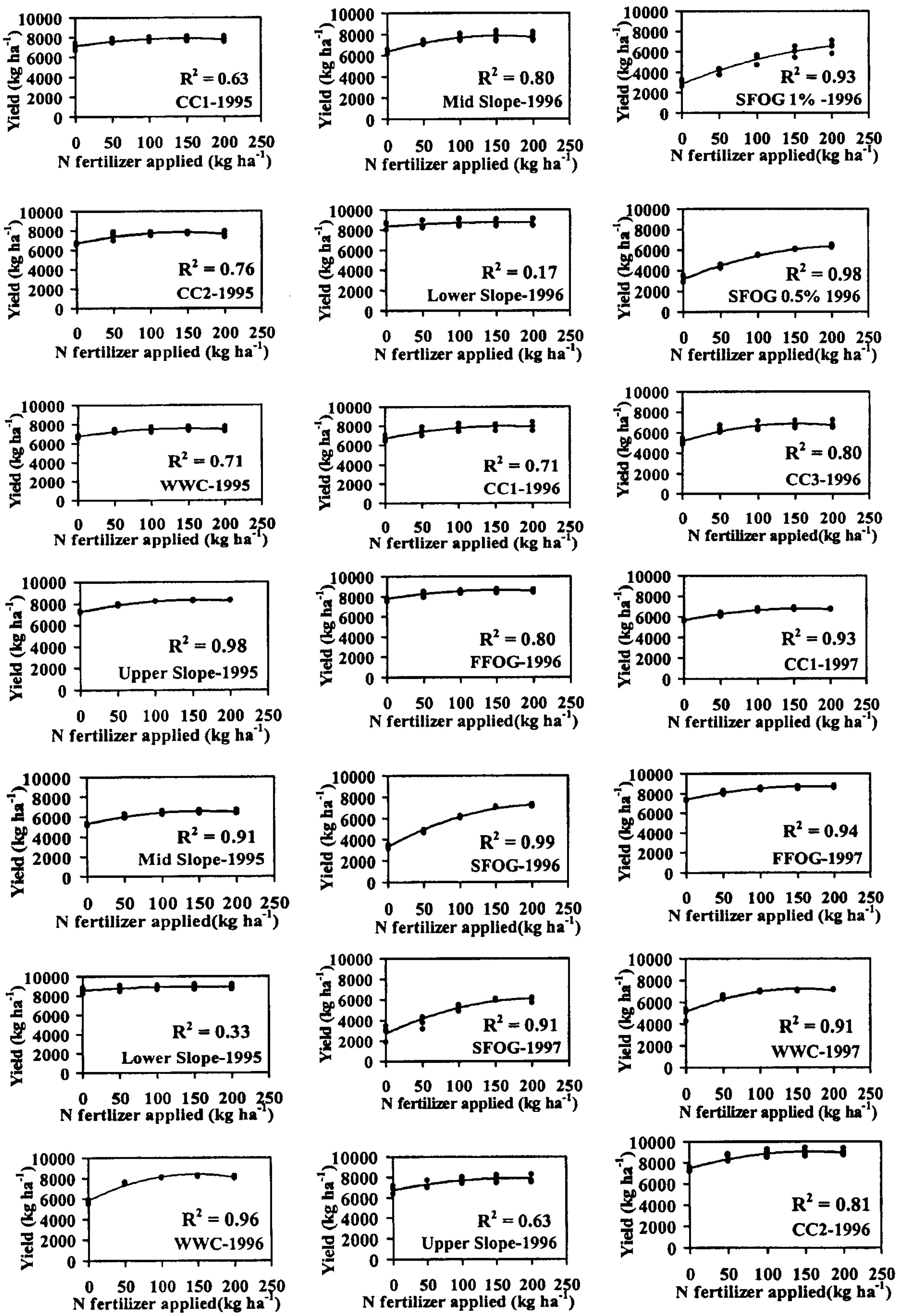

Fig 3. Corn grain yield response to N applied at all individual experimental sites.

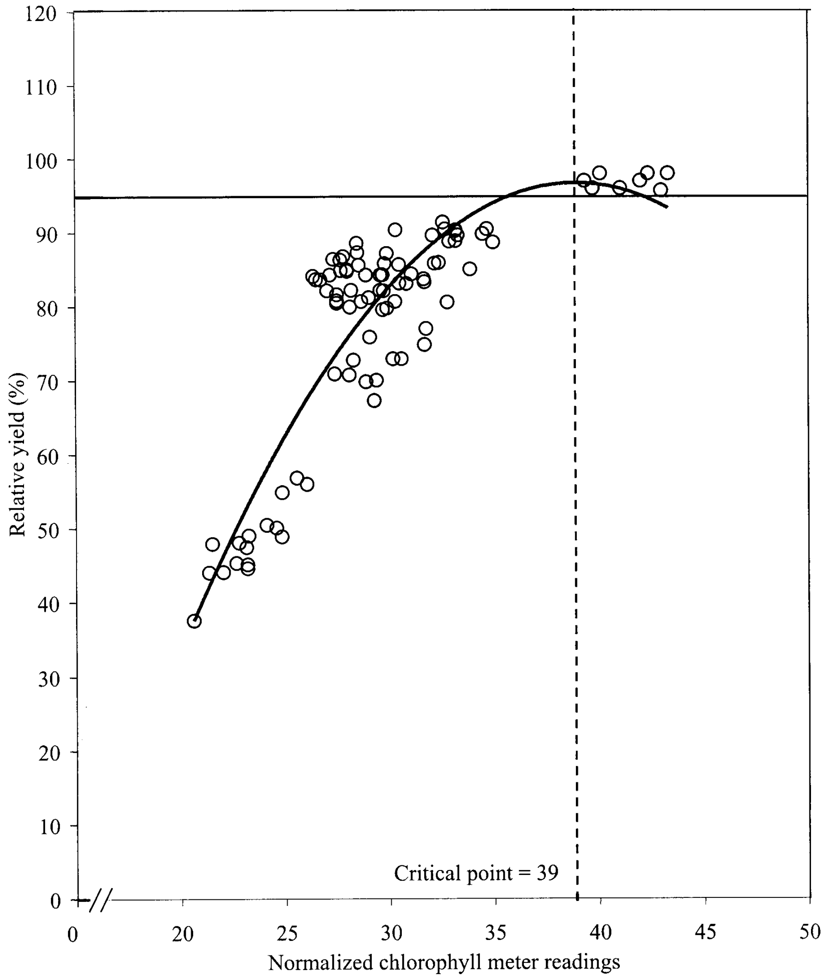

Fig 4. Relationship between normalized chlorophyll meter readings and relative yield (Cate and Nelson approach).

The CMR were correlated with soil NO_3-N in the 0- to 30-cm soil depth taken at the same time, and with the total N concentration of the leaf (detached after taking CMR for N analysis). MERN calculated for all experimental sites (pooled data) were linearly regressed with the CMR to determine the N requirement for corn grown under varying N availability conditions.

RESULTS AND DISCUSSION

Lower CMR values were observed for N deficient plots, (oily food waste amended plots) and higher CMR were observed for N sufficient plots (conventional corn and lower field slope positions). The relationship between CMR and soil NO_3-N content at the time of the CMR measurements is illustrated in Fig. 1. Nitrogen concentration of the same plant leaves also confirmed the variability in CMR as readings varied according to the change in leaf N concentration (Fig. 2).

A quadratic model was fit (R^2 = 0.88) to CMR data to determine the effect of N application, crop management conditions and corn hybrids on CMR (Table 4). The statistical analysis revealed that CMR were significantly affected by nitrogen application, crop management treatments (CMT) and corn hybrids (HYB). Contrast comparisons were made among different pairs of CMT × HYB interactions to determine response surface curve differences between HYB and CMT. Although five different corn hybrids were sown at different sites, a significant difference in CMR response surface curves was observed only among DK-306, Pioneer-3905 and Pioneer-3906. These hybrids responded significantly differently under all rates of FOG amendments. The difference among these hybrids under other crop management conditions was non-significant. Waskom et al. (1996) and Sunderman et al. (1997) have reported a significant difference among hybrids for CMR at different growth stages under similar fertilizer management conditions.

A comparison of the effect of crop management treatments (CC, WWC, FFOG and SFOG) reveals that CMR under SFOG were significantly lower compared to CC, FFOG and WWC. FOG application rate also significantly affected the CMR values and lowest CMR values were recorded from corn plants growing on plots where FOG was applied in spring at 20 Mg ha^{-1}. Lower CMR under SFOG can be attributed to the lower NO_3-N contents (N immobi-

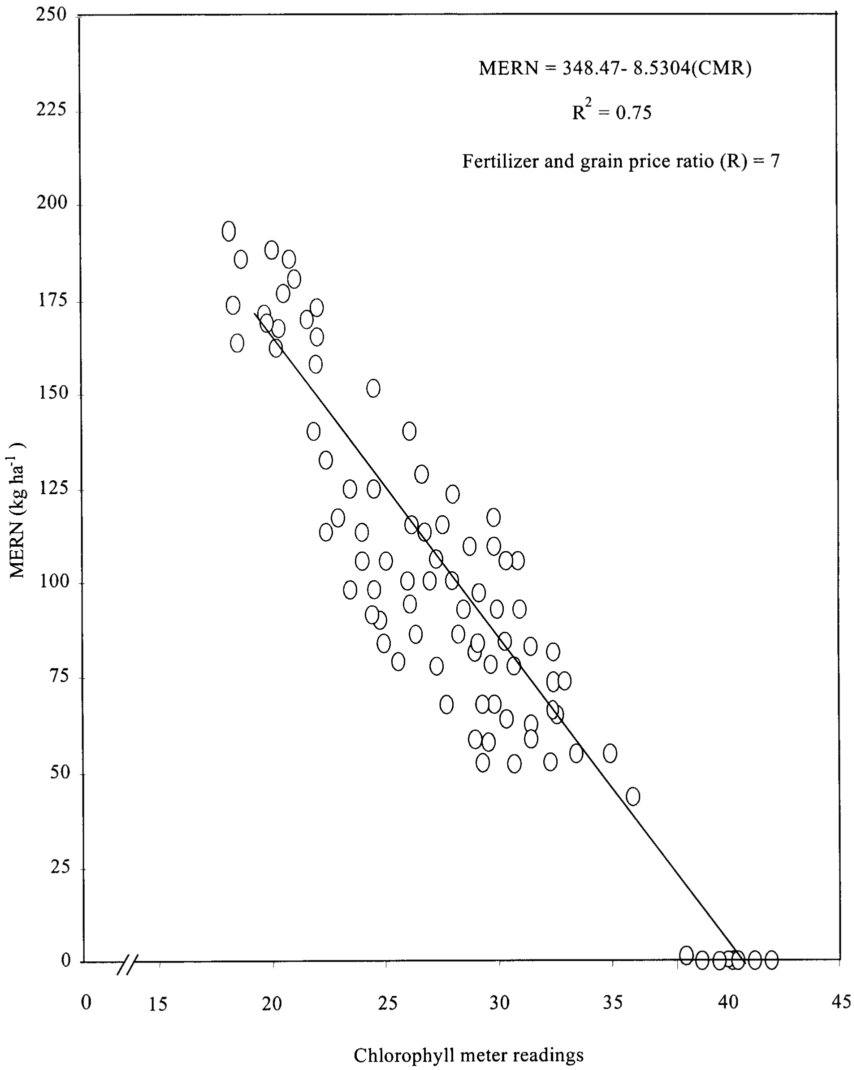

Fig 5. Relationship between chlorophyll meter readings of corn at the 5th to 6th leaf stage and maximum economic rate of N application (MERN).

lization) as compared to other crop management treatments. There was no significant difference among CC, FFOG and WWC treatments. Leaf greenness is influenced by a number of factors (hybrid, stage of growth and nutrients), but soil N availability most probably has the greatest effect within a field (Blackmer and Schepers 1995). Soil available N (NO_3-N) was immobilized during the decomposition of FOG and net N immobilization was significantly higher in SFOG amended plots compared to FFOG amended plots (Rashid and Voroney 2003).

A highly positive curvilinear response relationship (R^2 = 0.78) was observed when leaf N concentration (mg g^{-1}) data were pooled and plotted against CMR (Fig. 2). Most of the leaf N is in enzymes associated with chlorophyll (Chapman and Barreto 1997), so it follows that chlorophyll concentrations reflect crop N status (Blackmer and Schepers 1995), which reflects the soil N fertility status. Lohry (1989) showed that corn leaf chlorophyll content increases in relation to applied N similarly to grain yield. This has led to the use of a chlorophyll meter for sensing "greenness" as a means of determining when corn will respond to additional N fertilizer (Schepers 1992a). A significant positive correlation between chlorophyll and leaf N concentrations has been reported (Girardin et al. 1985; Wolfe et al. 1988; Lohry 1989; Wood et al. 1992).

A relatively strong curvilinear relationship (R^2 = 0.63 to 0.99) was observed between N application rates and grain yield for all individual experimental sites (Fig. 3). However, a poor correlation between corn grain yield and fertilizer N application rate was observed at lower slope position where initial NO_3-N contents were high and no response was observed (in terms of increase in grain yield) to additional N application. Lower slope positions collect N-rich topsoil from surrounding landscape positions as a result of redistribution during tillage (Pennock et al. 1994). As a result of this redistribution, these positions have high amounts of organic matter, total N (Gregorich and Anderson 1985), inorganic N (Jowkin and Schoenau 1998) and N mineralization (Pan et al. 1993) compared to soils in upper landscape positions.

Chlorophyll meter reading data are generally normalized by using the data from strips where maximum N fertilizer is applied, and relative corn yields have been used by other workers to plot the grain yield and CMR. The approach suggested in the literature is to use the Cate and Nelson (1965) method to separate the N responsive and non-responsive sites by determining the critical level of the CMR. Little attention has been given to calculating the fertilizer N requirement required below the critical level.

To examine this issue, we used the MERN as an agronomic indicator. MERN was calculated from the quadratic response of grain yield to N fertilizer application for each replication of each set of experimental conditions. MERN was plotted against CMR taken from the control plots (where N was not applied) and critical point was determined by taking the point where the linear line intersects the *x* axis i.e., chlorophyll meter readings (Fig. 5). The critical point determined in our studies is 41, which is higher than the critical point of 39 calculated from the same data by adopting Cate and Nelson approach (Fig. 4). Piekielek and Fox (1992) determined the critical point of 43.3 at the same crop growth stage but under different crop management conditions. They found that 24% of the sites were classified as outliers according to Cate-Nelson criteria. Our approach for determining the critical level is also different as we have not used the Cate-Nelson approach. Instead the point where the linear line intersects the *x* axis is used.

A strong inverse linear relationship (R^2 = 0.75) between MERN and CMR was observed (Fig. 5) and a linear model (MERN = 348.47 – 8.5304 × CMR) is therefore suggested for nitrogen fertilizer recommendations by using a portable chlorophyll meter for corn grown under varying degrees of N availability. MERN values were calculated for all experimental sites representing highly deficient (SFOG) to moderately deficient (FFOG and WWC), sufficient (CC) and excessive (lower slope position) available nitrogen.

The suggested model can be successfully used for N fertilizer recommendations for corn grown on a wide range of soil N availability levels under different soil and crop management conditions in Southern Ontario. Piekielek et al. (1995) adopted a similar approach at denting stage by plotting CMR against additional N needed for economic optimum yield. In our studies a decrease in CMR of one unit may increase the fertilizer requirements for corn by 9 kg N ha^{-1}.

CONCLUSIONS

Chlorophyll meter readings at five- to six-leaf stage (V_6) were used to calculate the N fertilizer recommendations at side dress time. The chlorophyll meter successfully detected the N deficiency on oily food waste amended plots and sufficiency on conventional corn and lower slope positions in the field in the plant at this growth stage. The model we have proposed can easily be used for N fertilizer application rates for each reading below the critical point (i.e., 41 in our studies). A decrease in chlorophyll meter readings of one unit may increase the fertilizer requirements for corn by 9 kg N ha^{-1}. Further research is required to test the suitability of this linear model under different crop management conditions in other geographical areas.

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